

FINAL CONTRACT REPORT

**ASSESSMENT OF THE PERFORMANCE OF SEVERAL ROADWAY MIXES
UNDER RAIN, SNOW, AND WINTER MAINTENANCE ACTIVITIES**

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ABSTRACT

The purpose of this study was to assess the relative functional performance, including skid resistance and splash and spray, of five hot-mix-asphalt (HMA) surfaces and a tinned portland cement concrete highway surface during controlled wet and wintry weather events. The study compared the way that these surfaces respond to various deicing and anti-icing snow removal and ice control techniques under artificial wintry conditions. In addition, the splash and spray characteristics of the surfaces during and immediately after rain were also evaluated.

The study focused on the surfaces placed within the all-weather testing area at the Virginia Smart Road. The winter maintenance techniques tested include the application of sodium chloride (salt) in granular, pre-wetted, and liquid forms. The snow removal and ice control measures that were used followed the recommendation of the FHWA Project T&E 28 and variations thereof. The experiments to compare the splash and spray characteristics of the mixes were conducted using artificial rain.

The study defined and tested a methodology for testing winter maintenance operations under controlled, artificial wintry events. The winter maintenance test results were inconclusive, as the various maintenance treatments were unable to significantly improve the functional condition of the road. Under the temperature and precipitation conditions encountered, there were no significant differences in the performance of the different surface mixes tested. However, conditions encountered did not correspond to conditions normally encountered with natural snow.

The researcher concluded that at temperatures at and just below freezing, artificial snow might not be appropriate for evaluating the effectiveness of winter maintenance chemicals. Studies that depend upon imitating the on-road attributes of natural snow, such as testing effectiveness of winter maintenance chemicals, should adhere to the ideal temperature-humidity guidelines for the snowmaking equipment.

The open-graded friction course appears to have enhanced spray and splash performance when compared with the dense HMA surface mixes; however, a more objective measure of splash and spray characteristics of the surfaces is needed to quantify the beneficial effect of this type of mixes. No visual difference in performance was observed among the other mixes.

INTRODUCTION

The cost of roadway snow and ice control in the United States is very high. Each year agencies spend approximately \$1.5 billion on maintenance activities, such as plowing, salting, and sanding road surfaces (Mergenmeier, 1995). In addition, it is estimated that \$5 billion is spent on indirect costs, including corrosion, water quality degradation, and other environmental consequences (U.S. Roads, 1997).

Two important factors in snow and ice control operations include determining the operations' effect on the safety and mobility of the public using the facilities, as well as determining the optimum amount of chemicals that need to be applied to a roadway to achieve a safe surface condition while minimizing the damage to the environment. When a wet or snow-covered surface freezes and produces a slippery surface, winter-maintenance operations are performed to bring the road surface to a bare-pavement condition or, at least, to a bare wheel-track condition. However, not all pavement surfaces respond in the same way to the application of different chemicals. The optimum chemical type and application rate that need to be applied to a roadway to achieve a safe surface condition depends on many factors, including surface condition, pavement temperature, type of pavement surface, dew-point temperature, and precipitation type and rates, among others.

The Virginia Smart Road offers a unique opportunity to test the effects of different winter maintenance operations, anti-icing/deicing chemicals, and application rates on both conventional and unconventional pavement surfaces. The Smart Road's all-weather-testing facility covers five different hot-mix asphalt (HMA) surface mixes and a conventionally tined portland cement concrete (PCC) surface. The HMA surfaces include several of the newest surface mixes in Virginia, such as Superpave™ mixtures, a stone matrix asphalt (SMA), and an open-graded friction course (OGFC).

In addition to material performance, the test bed provides an opportunity to compare the functional characteristics (e.g., comfort and safety) of the various surfaces under identical conditions. One of the primary safety issues is the functional reaction of surfaces to inclement weather conditions, including snow and ice events, as well as heavy rains. For example, some of the coarser mixes offer advantages when considering heavy truck loading, tire-spray reduction, and cross-drainage improvements. Unfortunately, these same surfaces have reputations as being problematic when subjected to wet-freeze conditions (Kandhal and Mallick, 1998). However, researchers have reported enhanced performance in some cases (Iwata *et al.*, 2002).

PROBLEM STATEMENT

Many of the surfaces placed on the Virginia Smart Road were new in Virginia at the time of their placement. Therefore, questions existed concerning the relative performance, in terms of durability and functionality, of the various materials. In particular, there were questions regarding the relative performance of the various HMA surface mixes under inclement weather, including the following:

- In heavy rains, which surfaces promote the best visibility?
- During snow and ice events, which maintenance techniques and/or application rates are most effective on each of the alternative surfaces?

PURPOSE AND SCOPE

The purpose of this study was to assess the relative functional performance, including skid resistance and splash and spray, of various HMA highway surfaces during controlled wet and wintry weather events. The study compared the way these surfaces respond to conventional snow and ice control techniques under wintry weather conditions. The effects of various deicing and anti-icing techniques on the various available surfaces were also compared. In addition, the *splash and spray* characteristics of the five HMA surfaces and a tinned PCC surface during and immediately after rain were also evaluated.

The study defines and tests a methodology for testing winter maintenance operations under controlled, artificial wintry events. The study focused on the surfaces placed within the all-weather-testing area at the Virginia Smart Road. The winter maintenance techniques tested include application of sodium chloride (salt) in granular, pre-wetted, and liquid forms. The snow removal and ice-control measures that were used followed the recommendation of the FHWA Project T&E 28 and variations thereof (Ketcham, 1998). The experiments to compare the splash and spray characteristics of the mixes were conducted using artificial rain.

LITERATURE REVIEW

This section presents a brief summary of the literature reviewed regarding winter maintenance practices and the assessment of the relative functional performance of highway surfaces during controlled wet and wintry weather events. Winter maintenance practices include a series of procedures and methods to enhance mobility and safety during and after wintry events by controlling ice formation and snow accumulation. The review of pavement functional performance assessment focused on methods for determining the relative level of service provided to roadway users during and immediately after rain, ice, and snowstorms.

Winter Maintenance Practices

There are several published investigations concerning winter maintenance operations and their effects on user safety and mobility. However, no records were found for tests performed under controlled, artificial precipitation.

The AASHTO *Guide for Snow and Ice Control* (AASHTO, 1999) provides complete coverage of all the issues related to winter maintenance operations, including basic principles, management, personnel, equipment, materials, weather information systems, operations, and safety and liability issues. The guide discusses two snow and ice-control strategies that involve

chemical treatment of roadways: deicing and anti-icing. This guide outlines a number of operational applications of chemicals, including solid, prewetted solid, and liquid forms.

The *Test and Evaluation Project No. 28: Anti-icing Technology Field Evaluation* (Ketcham *et al.*, 1998) included a series of field experiments to test different anti-icing practices and their effects on pavement conditions. The field evaluation included a two-winter, experimental anti-icing study in 15 states, and analysis of the experimental data.

Three different experiments were carried out in different states. They included dry and pre-wetted solid chemical application, liquid application and salt/abrasives mix application. These experiments were performed according to a standard protocol that allowed for consistent analyses of the data from all sites. Each experiment entailed applying an anti-icing treatment on a “test section” and a conventional deicing treatment on a “control section,” documenting the operations, and taking measurements and observations during a single storm. The data from all experiments were then compiled and analyzed to develop recommendations for *good* anti-icing practices. The project found that during a storm, pavement friction decreases with decreasing pavement temperatures, increasing precipitation rates, and decreasing traffic rates—even when successful anti-icing operations are being conducted. Pavement temperature was the most critical factor affecting friction, followed by precipitation rate and traffic rate.

The *Manual of Practice for an Effective Anti-icing Program* (Ketcham *et al.*, 1996), which resulted from the test and evaluation project, provides information for successful implementation of an effective anti-icing program. The manual includes information on five chemicals in use at the time (1996) for deicing and anti-icing. Appendix C of the manual recommends anti-icing actions for the following six general winter-weather events:

1. Light Snow Storm
2. Light Snow Storm with Period(s) of Moderate or Heavy Snow
3. Moderate or Heavy Snow Storm
4. Frost or Black Ice
5. Freezing Rain Storm
6. Sleet Storm

The NCHRP report *Feasibility of Using Friction Indicators to Improve Winter Maintenance Operations and Mobility* evaluated the feasibility of using friction indicators as tools for improving winter maintenance operations and mobility. Short-term and long-term implementation scenarios were developed in which friction measurements could be used to improve winter maintenance safety, operation, and mobility. Two surveys were conducted with field practitioners and other knowledgeable sources, and responses indicated that using friction measurements would improve winter maintenance operations. The study also found that analyzing information collected from low-cost and reliable friction-measuring devices and other data, such as pavement temperature, traffic, and weather conditions, could be useful for allocating snow-fighting resources in real-time. Forecasting surface friction based on models that relate data such as temperature and traffic was also identified as a promising technique for improving winter maintenance operations, but further research is needed in this area (Al-Qadi *et al.*, 2002).

The Minnesota Department of Transportation (MnDOT) is developing a simple chart to determine the proper chemical to use for winter storm maintenance. The chart considers the ice melting capacity of chemicals, ambient temperature, pavement temperature, humidity, and anticipated precipitation. The guidelines will be tested in the field. Specific areas of the state will be commissioned to work exclusively with the charts and Road Weather Information System (RWIS) when making chemical de-icing and anti-icing chemical applications. Results will be monitored through MN/DOT maintenance indicators, and the effectiveness and trustworthiness of the streamlined charts will be evaluated based on these results (MnDOT, 2003).

Evaluation of Winter Maintenance on Porous Asphalt Pavements

Coarse open HMA mixes, such as the OGFC, offer advantages when considering tire spray reduction and cross-drainage improvements. However, the limited research efforts conducted to this point have yielded contradictory conclusions regarding their performance under winter conditions. While some reports indicate that these mixes are problematic when subjected to wet-freeze conditions (Kandhal and Mallick, 1998; Heystraeten and Diericx, 2002), others have reported enhanced performance (Iwata *et al.*, 2002).

Research conducted in Japan comparing the performance of porous asphalt pavement with conventional asphalt pavement under winter conditions (Iwata *et al.*, 2002) yielded the following findings:

- The road surface temperature of porous asphalt pavement is about 0.2°C lower than that of the traditional asphalt pavement during snowy conditions; however, this is not significant in terms of snow and ice control.
- During snowfalls, the road surface conditions of both pavements were similar.
- The salinity concentrations on both road surfaces were not significantly different.
- Except for compacted snow conditions, the porous asphalt pavements supply a higher friction number than do dense-asphalt pavements.

The study concluded that because of the higher friction supplied by the porous asphalt pavement, accidents may be reduced under snowy and icy conditions. Moreover, it found that there was no need to modify winter maintenance methods on porous asphalt pavement (Iwata *et al.*, 2002).

On the other hand, research conducted in Belgium by Heystraeten and Diericx (2002) found that the porous characteristics of the pavement surface reduces the amount of active chemicals on the surface; thus, porous surfaces require larger application rates of traditional de-icing salts. This implies that winter maintenance crews have to refill sooner or that special mixtures of de-icing salts have to be used to obtain satisfactory performance.

Splash and Spray Measurements

A few studies have been conducted on the splash and spray characteristics of pavement surfaces. Nicholls and Daines (1992) reported on the Transport and Road Research Laboratory's (TRRL) development and use of a system to measure spray. The device consisted of an infrared light emitter and detector that measure the light back-scattered from the droplets of water (spray) generated by a passenger car. A series of lenses, filters, and diffusers were developed to render the system insensitive to extraneous light and to minimize the effect of spray deposited on the lenses. The researchers developed prediction models for spray, which included factors such as surface material type, rainfall, total rainfall in the two hours prior to the test, vehicle speed, texture depth, and hydraulic conductivity.

Yeo and Foley (1997) also included the potential for spray suppression in a study of two concrete and five bituminous surfaces, including an OGFC, near Melbourne, Australia. A spray measurement system based on the TRRL system was developed. The spray measurement system was comprised of the original TRRL emitter and detector with new circuitry and data logging hardware and was mounted in a Sideways Force Coefficient Routine Investigation Machine (SCRIM) that was used to measure the sideways force coefficient. The authors indicated that the amount of water that is spread by the SCRIM may not be sufficient to assess the drainage capability of the different mixes.

Further studies used a water truck that sprayed the pavement just before the SCRIM truck. These studies allowed researchers to measure a reduction of up to 90% in the spray produced on OGFCs with respect to that produced on dense graded mixes in the first three to four years after construction. After this time, the benefit was minimal (Yeo et al., 2001).

METHODS

General

The experiments to test the behavior of the different pavement surfaces under rainy and wintry conditions were conducted at the all-weather-testing facility of the Virginia Smart Road. The experiments were confined to the portion of the roadway serviced by the artificial rain and snowmaking equipment. The pavement within this area includes five pavement surfaces (including several HMA surface and a tined PCC). Each section is approximately 300-ft long and two 12-ft lanes wide; Figure 1 illustrates the layout of the evaluation site.

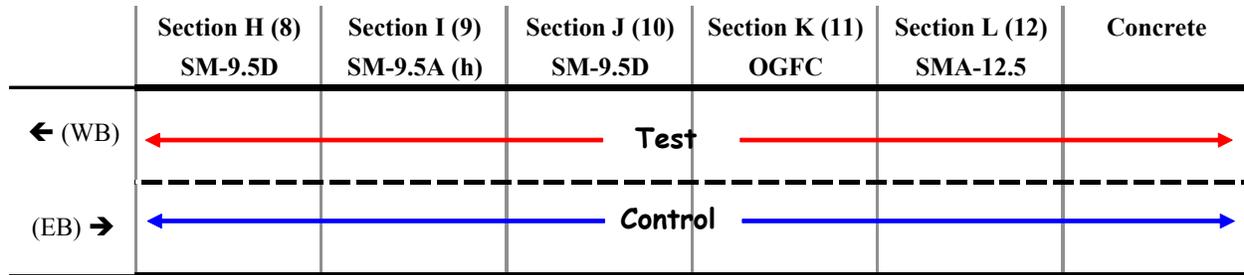


Figure 1. Layout of pavement sections within the Smart Road All-Weather Facility

The majority of the tests were conducted using some form of frozen or freezing precipitation. In addition, a limited number of experiments used rain to compare the driving conditions of the various surfaces during rain-only events. Both measurements of surface conditions and visual observations were used to evaluate the functional performance of the various surfaces. Environmental conditions during the tests were also recorded.

HMA Surface Mix Properties

The wearing surface mixtures used on the flexible pavement sections of the Virginia Smart Road include five different SuperPave™ mixtures (9.5 mm or 12.5 mm nominal maximum aggregate sizes [NMS]), a 12.5 mm stone matrix asphalt (SMA), and a 12.5 mm OGFC. The experiment investigated the performance of four of these mixes, which overlap the all-weather testing facility, as indicated in Figure 1. The mixes were produced through a batch plant. The average volumetric properties determined in the laboratory for these mixes are summarized in Table 1. Although every effort was made to match the design properties, the OGFC failed to meet current specifications because it was constructed with lower asphalt content than the design target.

Table 1. Laboratory Measured Properties of the Wearing Surface HMA

Section	Mix	Binder	NMS	MS	Pb	PP 9.5	PP 4.75	PP 2.36	PP 1.18	PP 0.6
E-H	SM-9.5D	PG 70-22	9.5	12.5	5.9	93.8	61.6	41.4	29.2	20.1
I	SM-9.5A (h)	PG 64-22	9.5	12.5	5.2	95.6	56.3	38.9	29.1	21.6
J	SM-9.5D	PG 70-22	9.5	12.5	4.9	92.3	53.5	36.5	25.8	18.0
K	OGFC	PG 76-22	12.5	19	5.5	80.8	13.6	1.8	1.4	1.3
L	SMA-12.5D	PG 70-22	12.5	19	6.8	86.0	36.5	24.6	21.1	18.4

Anti-Icing and Deicing Experiments

The tests involving wintry conditions used the general approach for the anti-icing and deicing experiments that was used as a part of the SHRP H-208 (Blackburn, 1994) and FHWA T&E 28 (Ketcham *et al.*, 1996) projects. The west-bound (WB) lane was used as the *test* section, and the east-bound (EB) lane was used as the *control* section for each pavement type (See Figure 1). Only the standard chemical used in VDOT specifications, sodium chloride (salt), was used in granular, pre-wetted, and liquid form. Initial application rates were consistent with those recommended by the FHWA T&E 28 project, but some of the later experiments used higher rates. Each anti-icing/deicing experiment consisted of applying the chemicals on the test lane but not on the control section, producing the snow, plowing the surface, and collecting all the pertinent data. Several experiments were conducted over the course of the project, with variable environmental conditions, precipitation types, maintenance actions (type of chemical treatment), and chemical application rates, as presented in Table 2. Surface temperatures were closely monitored, and an attempt was made to have experiments in three temperature ranges: -1 to -4°C, -4 to -7 °C, and -7 to -10 °C. However, the experiments were highly dependent on the weather conditions and availability of the needed equipment.

Table 2. Summary of Anti-icing Experiments

Test	Test Date	Applied Chemical	Application Rate	Pre-wetting Rate
I	2-12-2002	Dry solid sodium chloride	200 lb/lane-mile	None
II	3-04-2002	Solid Sodium chloride prewetted with liquid calcium chloride	200 lb/lane-mile	10 gal/ton
III	3-06-2002	Solid sodium chloride prewetted with liquid calcium chloride	300 lb/lane-mile	10 gal/ton
IV	3-23-2002	Solid sodium chloride prewetted with liquid calcium chloride	300 lb/lane-mile	10 gal/ton
V	1-27-2003	Solid sodium chloride prewetted with liquid calcium chloride	300 lb/lane-mile	10gal/ton
VI	2-06-2003	Liquid sodium chloride solution	40 gal/lane-mile	None

Anti-Icing/Deicing Experimental Procedure

The procedure used to conduct the anti-icing/deicing experiments had to be adjusted as the research project progressed because it was the first experiment of this type in the world, and several difficulties were encountered during the successive tests. The main problem encountered was finding the appropriate environmental conditions to produce snow. Because of this reason, most experiments had to be conducted during nighttime or very early in the morning. Other problems that had to be solved included the uniformity of the coverage and the quality of the snow produced. In spite of the difficulties, after several iterations, a general working procedure was defined as follows:

1. The research team planned the approximate timing for the experiment based on available weather predictions; both the National Oceanographic and Atmospheric Administration (NOAA) Blacksburg site and the Weather Channel predictions were used for this purpose.
2. The sections' boundaries were marked with traffic cones.
3. The automatic pavement temperature monitoring system was started, and the temperature (1.5 in. below the surface) was monitored.
4. Once the temperature reached the pre-defined target, two pavement surface temperature readings were collected for each section and lane using an infrared thermometer.
5. If the temperature was appropriate, the video recording equipment was started and the lights were turned on.
6. The spreader was set to the appropriate application rate based on the predicted application speed using the calibration spreadsheet for the spreader used. The spreader was calibrated at the beginning of the experiment in accordance with VDOT procedures.
7. Snow generation was started (Figure 2[a]).
8. The spreader applied the chemical to the test sections. In the case of the liquid application, the chemical was applied before the start of snow generation.
9. Traffic was started (and counted) on both the test and control sections, but different vehicles were used to avoid contaminating the control section. One truck and one car were used on each lane (Figure 2(b)).
10. When the snow accumulation reached, on average, approximately 2 in. in untreated, non-traffic areas, and some accumulation (approximately 1 in. of packed snow) had occurred on the wheelpaths, the snow generation was stopped and the road was plowed twice (Figure 2[c]).
11. Friction was measured using a standard ASTM trailer (ASTM E274). Three Skid Number (SN) measures were taken on each section and lane without activating the water spray system. All the tests were conducted using the smooth tire (ASTM E 524) in the uphill direction because of safety reasons (Figure 2[d]).
12. The surface condition in the wheel paths of the test and control sections was visually evaluated by the research team using a simple subjective rating.
13. The final surface temperature was recorded using the infrared thermometer.

Snow Generation

The Smart Road's snowmaking equipment and facilities include a 500,000-gallon water tank and 80 aluminum snow towers. The towers span approximately a 0.5-mile section of the road and are spaced at 33-ft (10 m) intervals. At 40-ft long, the towers can be adjusted for use at various heights, but they are most commonly used at a height of 25 ft. At full capacity, the towers can produce up to 1 ft of snow per hour.



a) Artificial Snow Initiation



b) Traffic Application



c) Plowing



d) Skid Testing

Figure 2. Illustration of Anti-icing/ Deicing Experimental Procedure

The snowmaking system uses public drinking water; therefore, the water tank is used to avoid placing large burdens on municipal facilities during snow production. During snowmaking, water from the tank is pumped at 300 to 500 psi. The amount of water used varies according to the size of nozzle used on the snow towers. For example, when a small (model 5010) nozzle is used and water is pumped at 300 psi, 2.7 gallons per minute are used by each nozzle. The larger (model 5020) nozzle uses considerably more water at the same psi—5.5 gallons per minute. Each snow tower uses four nozzles. Depending on weather conditions and snow quality, the system uses between 140,000 to 220,000 gallons of water per one acre-foot of snow. In addition to its function as a buffer for municipal water facilities, the water tank is used to avoid water shortages and subsequent problems during snow production.

The water arrives in the tank at approximately 50 to 70°F. To produce snow, the water must be cooled to approximately 30 to 32°F before being pumped to the snow towers. Cooling is accomplished through the use of a recirculator that, in effect, creates a cold battery inside the tank. In optimal conditions, the water on the top of the tank forms a layer of ice, while the water below it resists freezing due to recirculation and pressure. Moreover, the chemicals present in the municipal water lower the temperature at which it will freeze.

During snow production (Figure 3), the chilled water is drained out of the tank into a wet well, from which it is drawn out by pumps to the snow towers. The water travels through the ground via a concrete-lined pipe, which acts as an insulator to lessen the transfer of ground heat to the water.



Figure 3. Snow Generation

The aluminum snow towers contain three nested pipes: the water flows through the outer pipe, and cooled, compressed air travels through the center pipe (the middle pipe is not generally used for snowmaking). The outer pipe is used to carry the water because it allows the cold air temperatures to transfer to the water, thus cooling the water further and combating any increases in temperature that may have occurred while the water flowed underground. The pipes feed four nozzles on the tip of the tower. When sprayed out of the nozzles, the water is hit with dry/cool air blown from air jets. This air has been compressed through a three-stage turbine compressor that uses two intercoolers, an aftercooler, and a moisture separator to produce cold, dry air.

The purpose of this cold, dry air is to atomize the water sprayed from the nozzles as finely as possible because smaller droplets freeze more easily. In addition, evaporative cooling caused by the atomization contributes to the freezing process. However, the quality and quantity of the snow produced depends largely on the ambient weather conditions. The ideal snowmaking conditions are dry and cold. However, temperatures of 21.2°F and below are optimal, regardless of the humidity level. Yet as temperatures begin to rise, lower humidity levels are required to produce snow (see Table 3). For example, high-quality snow can be produced at temperatures as high as 28.4°F, but only under humidity levels of 20 percent or below. As the temperatures and humidity levels rise, the quality of the snow produced begins to dramatically decrease. However, snow can still be produced at temperatures as high as 37°F, given humidity levels of ten percent or less.

Table 3. Snowmaking Temperature and Humidity Guidelines

Air Temperature °F	Relative Humidity %									<div style="display: flex; flex-direction: column; align-items: center;"> <div style="width: 20px; height: 10px; background-color: #00FF00; margin-bottom: 5px;"></div> Excellent <div style="width: 20px; height: 10px; background-color: #FFFFFF; margin-bottom: 5px; border: 1px solid black;"></div> Poor <div style="width: 20px; height: 10px; background-color: #FFFF00; margin-bottom: 5px;"></div> Rain </div>
	20%	30%	40%	50%	60%	70%	80%	90%	100%	
	Wet Bulb Temperature °F									
17.6	12.7	13.3	13.8	14.5	15.1	15.8	16.3	16.9	17.6	▲ Ideal Snowmaking Condition ▼
19.4	14.0	14.7	15.4	16.0	16.7	17.4	18.0	18.7	19.4	
21.2	15.4	16.2	16.9	17.6	18.3	19.0	19.8	20.5	21.2	
23.0	16.9	17.6	18.3	19.0	19.9	20.7	21.4	22.3	23.0	▲ Marginal Snowmaking ▼
24.8	18.2	19.0	19.8	20.7	21.6	22.3	23.2	23.9	24.8	
26.6	19.6	20.5	21.4	22.1	23.0	23.9	24.8	25.7	26.6	
28.4	20.8	21.9	22.8	23.7	24.6	25.5	26.6	27.5	28.4	▲ Snowmaking Not Possible ▼
30.2	22.3	23.4	24.3	25.3	26.2	27.3	28.3	29.3	30.2	
32.0	23.7	24.6	25.7	26.8	27.9	28.9	30.0	30.9	32.0	
33.8	25.0	26.1	27.3	28.4	29.5	30.6	31.6	32.7	33.8	
35.6	26.4	27.5	28.8	29.8	31.1	32.2	33.3	34.5	35.6	
37.4	27.9	28.8	30.2	31.6	32.5	33.8	35.1	36.3	37.4	
39.2	29.1	30.4	31.0	32.9	34.2	36.4	36.7	37.9	39.2	
41.0	30.6	31.8	33.1	34.6	35.8	37.0	38.5	39.7	41.0	

When snow forms naturally, water droplets freeze around dust particles or ice and grow larger and stronger as they make their long trip to the ground. However, man-made snow must form more quickly. For example, snow produced by the Smart Road’s weather towers has as little as 25 ft in which to form strong, hard flakes, or grains. To combat this problem, the Smart Road snowmaking system uses artificial particles, called nucleating proteins, in the water. This additive is necessary because pure water is difficult to freeze, and like in nature, snowflakes

grow from ice crystals formed around dust or other particles. As these ice crystals fall to the ground, more crystals are formed around them, creating a snowflake. Therefore, it is extremely important that the water emitted from the snow towers is cold enough that it is on the verge of freezing. Once it is sprayed from the nozzles, it is quickly frozen by the super-cooled, compressed air that is blown from the air jets on the nozzles.

The snowmaking procedure used for this study was changed several times in an attempt to match natural winter events as closely as possible. The first experiments were conducted using larger (5020) nozzles (that produced a significant amount of snow in a short amount of time) and only half of the towers (every other one). Although this tower configuration reduced the amount of towers that had to be “converted” to produce snow, it did not produce adequate coverage.

The bigger nozzles produced the needed snow quickly, but the snow generated by these nozzles did not allow for safe driving on the road while the snow was being produced because the visibility was very low. Thus, the snow generation had to be interrupted during the application of the chemicals with traffic. This created some problems because on the coldest days (when the best quality snow can be produced), the water in some of the nozzles froze when the flow was interrupted, thus creating a non-uniform coverage. In addition, the large nozzles produced a very “wet” snow (with a very high water equivalent when compared with natural snow). Consequently, the final procedure used all the towers and smaller (5010) nozzles. It was also necessary to adjust the towers manually (rotating them and changing their elevation) during the experiments to create a more uniform coverage.

Data Collection

The following parameters were collected:

1. Surface temperature on each pavement subsection before and after the experiment, using an infrared thermometer.
2. Pavement temperature in each pavement subsection every 15 minutes during the experiment, using thermocouples embedded in the pavement approximately 1.5 in below the surface.
3. Air temperature for the area every 15 minutes during the experiment, using thermocouples located approximately 2 ft from the edge of the road and 6 in. above the ground.
4. Traffic counts on the test and control section.
5. Chemical application rate, based on the calibration chart for the spreader.
6. Time of plowing and chemical application operations.
7. Subjective observations of the condition in the wheel paths of the test and control sections after plowing. The pavement was graded according to a simple three-level subjective rating (as shown in Table 4).
8. Continuous video of the conditions during testing.

9. Pavement friction (three measurements per section/ lane) after plowing, using a standard ASTM trailer (ASTM E 274), without activating the water spray system, using the smooth tire (ASTM E 524) and in the uphill direction.

Table 4. Subjective Pavement Condition Evaluation

Condition	Color	
	White	Black
Slippery	Ice	Ice
Snow Covered	Snow	--
Wet.	--	Wet / Slush

-- = Not applicable

Analysis

The analysis of the data collected is presented in the Discussion section of this report. For each experiment, the friction measurements and subjective ratings taken after the treatments were compared. Analyses of Variance (ANOVA) were conducted to identify significant differences among treatments (test and control) and pavement surfaces. Tukey box plots were prepared to allow a graphical comparison of the conditions in the various sections after the control and test treatments.

Wet No-Freeze Experiments

Only two experiments (on the same date) were conducted under rain-only conditions. The relative functional performance and driver visibility was subjectively evaluated during and after the rain. Simulated rainfall was applied to the various surfaces, and the reaction of these surfaces was evaluated visually and using a digital camera.

Wet No-freeze Experimental Procedure

The wet no-freeze experiments were conducted in the spring, when there was no danger of the pavement freezing or of natural precipitation “contaminating” the test conditions. The experiment consisted of producing rain and evaluating the splash and spray produced by a heavy (tandem) truck driving at approximately 30 mph during the rain and shortly after the end of the precipitation.

Data Collection

The following parameters were collected:

1. Pavement temperature in each pavement subsection every 15 minutes during the experiment, using thermocouples embedded in the pavement approximately 1.5 in. below the surface.
2. Air temperature for the area every 15 minutes, using thermocouples located approximately 2 ft from the edge of the road and 6 in. above the ground.

3. Surface temperature was measured using a laser thermometer.
4. Observations of the condition in the test sections during and after the rain.
5. Continuous video of the conditions during testing.
6. Visual observation of the spray and splash produced by a heavy (tandem) truck traffic during and after the rain.

RESULTS

Anti-Icing and Deicing Experiments

Six anti-icing/ deicing tests were conducted, as indicated in Table 1. Tests were conducted using dry solid, pre-wetted solid, and liquid chemical solution. The parameters used to evaluate the effectiveness of the applied treatments included visual inspection and friction (friction number). The plowing effort was not considered because the number of plows was consistent in all tests.

Pavement Skid Resistance

Table 5 presents the average Skid Number (SN) measured on the test and control lanes for each section and test date. The skid numbers were measured using a smooth tire (ASTM E 524) without applying the water to the pavement, as called for in the standard procedure (ASTM E 274). In all cases, the friction numbers were very low, indicating the applied treatments' failures to return the pavement to safe conditions. Possible explanations for these failures are provided in the following section. Figures 4 and 5 present the average friction test speed and skid number, as well as the pavement and surface temperature on all sections for the six tests conducted.

Table 5. Summary of Friction Numbers Measured on the Test Lane and Control Lane

Test	Experiment	Section					
		H	I	J	K	L	Conc.
I	Test	15.2	16.5	14.7	15.2	18.7	17.7
	Control	14.9	15.8	15.8	16.5	16.5	13.8
II	Test	18.6	17.6	18.1	21.6	19.0	21.2
	Control	18.5	19.7	16.7	18.4	18.9	18.5
III	Test	18.5	14.0	13.5	16.2	13.4	15.6
	Control	17.2	22.3	16.6	11.0	12.2	14.1
IV	Test	12.6	11.1	13.4	16.8	15.7	16.3
	Control	14.9	25.5	15.2	14.8	14.0	18.2
V	Test	19.7	19.7	87.9 ⁽¹⁾	25.0	21.7	22.6
	Control	39.9 ⁽¹⁾	19.9	91.0 ⁽¹⁾	20.5	22.0	21.0
VI	Test	11.9	15.4	14.7	18.5	13.7	15.1
	Control	15.0	15.4	16.4	15.7	16.0	17.5

⁽¹⁾ Sections were not fully covered with snow because of problems with some of the snow towers.

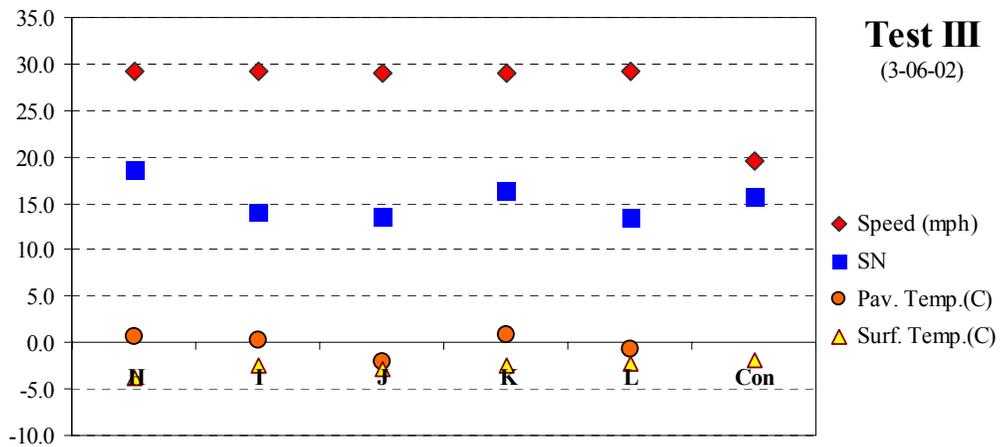
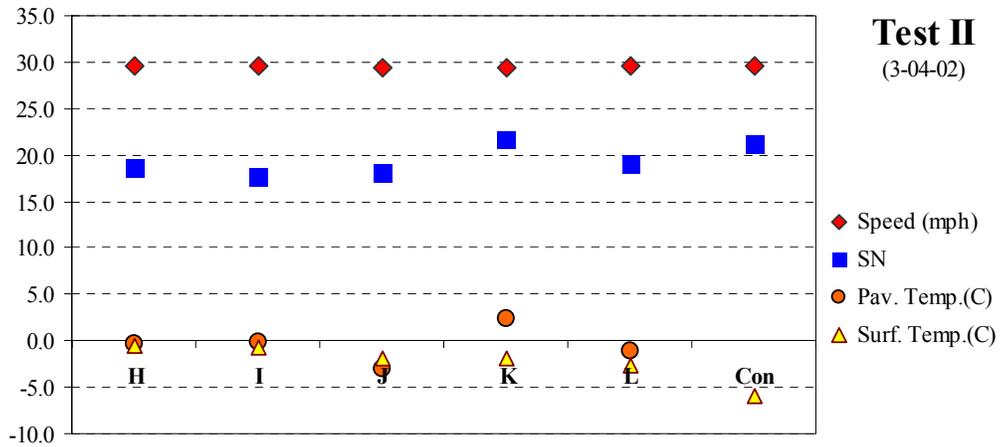
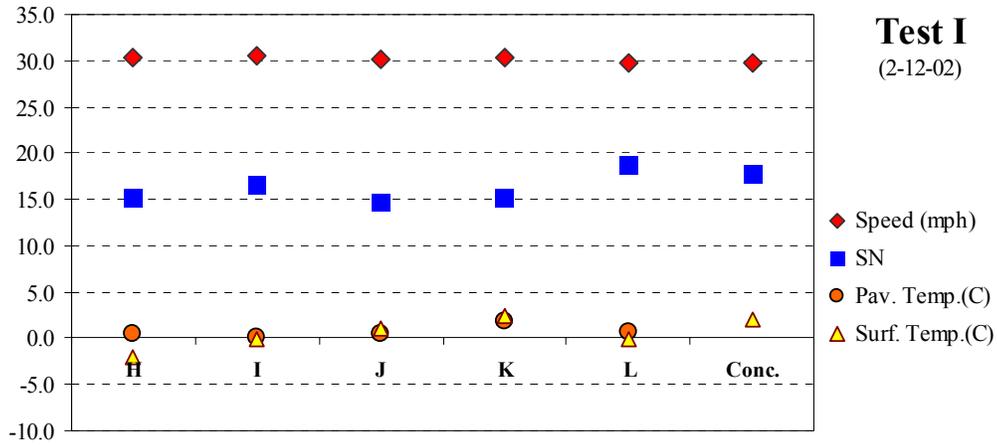


Figure 4. Summary of Test Results - Experiments I Through III

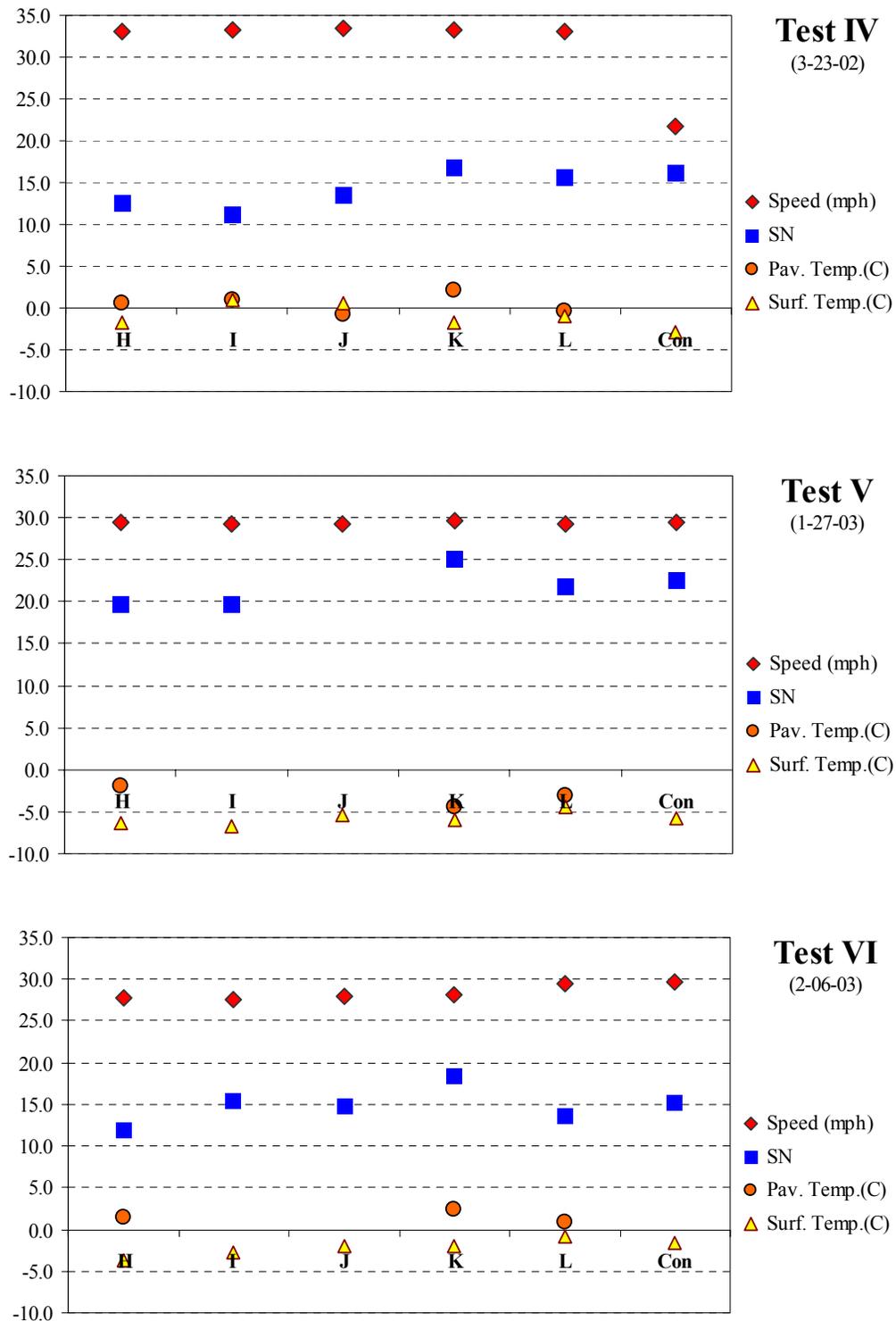


Figure 5. Summary of Test Results - Experiments IV Through VI

Notes: On 1-27-2003 and 2-06-2003 no pavement temperature data was collected for sections I and J because the data acquisition system was not functional. The SN measured on section J on 1-27-2003 was very high (89) because that section was not covered with snow due to problems with some of the snow towers.

There are no sensors in the concrete section; therefore, the pavement temperature could not be measured. Except for test V, all the tests were conducted in the highest temperature range (-1 to -5°C). In a few cases, the pavement temperature 1.5 in. below the surface was slightly above freezing.

The charts show that all sections performed similarly. Furthermore, the OGFC (Section K), on average, has comparable or slightly higher skid number than the rest of the HMA surfaces.

Visual Evaluations

The “average” visual evaluations for all the tests are presented in Table 6. A subjective “average” was determined based on the opinion of the three visual evaluators available for each experiment. Although no significant operational difference in performance was observed among the different surfaces, the evaluators noted that snow coverage was not uniform. This was due to limitations of the snowmaking equipment, especially on windy days, and is a possible source of variation in the experiment. However, even in the area where snow coverage was minimal within a specific surface type, for most tests, the evaluators felt friction values appeared to be uniform throughout the section. This could not be confirmed objectively due to the limitations of the friction testing equipment, which can only take discrete measurements of friction. The use of friction-measuring devices that continuously measure pavement friction along the sections could help overcome this limitation. It is interesting to note that researchers did not observe a significant difference among the test and control sections, indicating that the maintenance treatments were not very effective, as discussed in the following sections.

Table 6. “Average” Subjective Evaluations for the Test Sections

Test	Section H	Section I	Section J	Section K	Section L	Concrete
I	Snow	Snow	Snow	Snow/Ice	Snow/Ice	Snow/Ice
II	Snow/Ice	Snow/Ice	Snow/Ice	Snow/Ice	Snow/Ice	Snow/Ice
III	Slush/ Snow	Slush/Snow	Slush/ Snow	Snow/Ice	Ice/ Slush	Ice/ Slush
IV	Ice	Ice	Ice	Snow/Ice	Ice	Ice
V	Snow/Ice	Snow/Ice	Dry*	Snow/Ice	Snow/Ice	Snow/Ice
VI	Ice	Ice	Ice	Ice	Ice/ Slush	Ice

* This section was not uniformly covered with snow because of problems with the snow making equipment.

Wet No-Freeze Experiments

The two experiments using only wet precipitation were conducted on October 9, 2002. Figure 6 shows the initiation of the artificial precipitation as well as the truck used during the experiments. The splash and spray generated by the truck was evaluated subjectively by researchers driving closely behind the truck and taking pictures.



a) Artificial Precipitation Initiation



b) Testing Truck

Figure 6. Wet No-Freeze Experiment Illustration



a) SM-9.5-D (Section J), During Rain



b) OGFC (Section K), During Rain



c) SM-9.5-D (Section J), After Rain



d) OGFC (Section K), After Rain

Figure 7. Splash and Spray Comparison

The OGFC was beginning to experience premature distress as a result of the lower AC content, but it remained functionally representative of the surface type for the duration of the testing. The OGFC appears to have enhanced spray and splash performance when compared with the dense HMA surface mixes. The subjective evaluations (Figure 7) showed that the OGFC surface provided significantly less splash, especially soon after the precipitation, as presented in Figure 7 (c) and (d). During rain, the differences were less noticeable, as presented in Figure 7 (a) and (b). However, the poor condition of the OGFC may have contributed to reducing the effectiveness of this surface during rain. A more objective way of measuring splash and spray characteristics of the surfaces would be required to quantify the beneficial effect of these types of mixes. No significant difference in performance was observed among the other surfaces.

DISCUSSION

Anti-Icing and Deicing Experiments

The skid numbers (SN) for all the tests are summarized in Figures 8 through 13. The plots compared the maximum, average, and minimum SN measured on the control (CL) and test (TL) lanes for all the sections. It must be noted that during experiment V (1-27-03), some of the towers froze and, therefore, some of the sections (mainly H, J, and parts of section K) did not receive adequate snow coverage.

The plots appear to indicate that none of the sections showed a significant difference in performance under the treatments applied. Furthermore, the plots also reinforce the fact that there were no clear differences between the test and control lanes, which indicates that the treatments applied in the test section were not effective. This happened in spite of the fact that, in several of the tests, the chemical application was higher than what is normally used by VDOT maintenance crews.

The maintenance treatments' inability to improve the condition of the road is suspected to be due to the quality of the snow. The snowmaking equipment produced an artificial snow that may have been too wet for this type of testing; while normal snow has an equivalent water coefficient of 1:10 (1 in. of equivalent water for every 10 in. of snow), the water equivalent for the artificial snow was, on average, approximately 1:4. The extra amount of water could have diluted the chemicals and reduced their effectiveness. Snow produced on a very cold day while testing the towers had a visual quality very similar to that of natural snow. However, such low temperatures were not reached during any of the experiments.

Another factor that may have had a negative impact is the limited amount of traffic applied; the traffic applied may have not been enough to facilitate the dilution of the chemical and the formation of a liquid layer with a low condensation point that would prevent the bonding between the pavement and the packed snow. However, the research team felt that the traffic applied did not differ substantially from that of a typical rural road in Virginia during a winter storm.

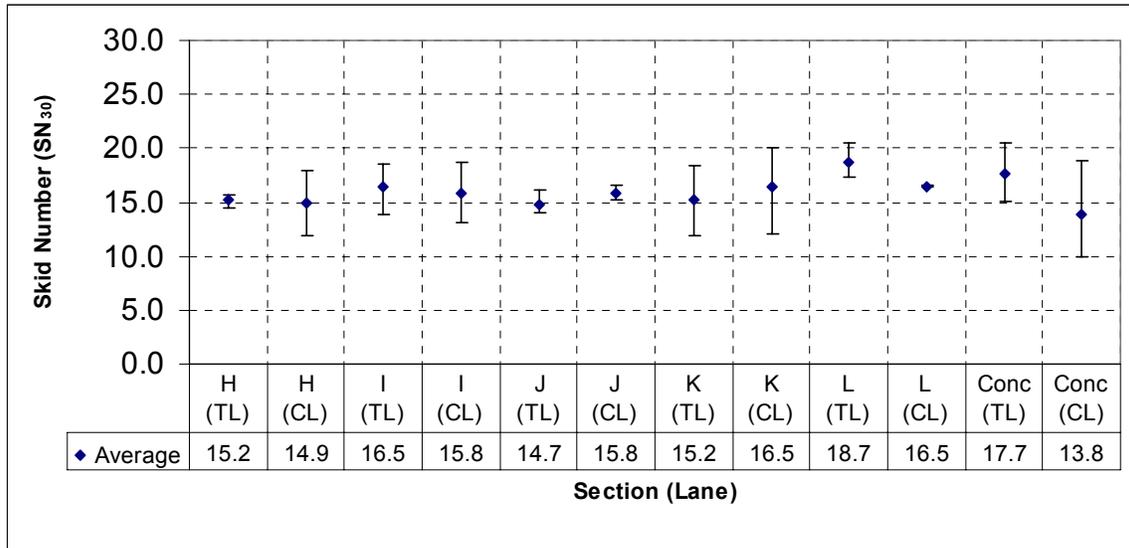


Figure 8. Maximum, Average, and Minimum Skid Measurements after Plowing for the Test (TL) and Control (CL) Lanes - Experiment I (2-12-02)

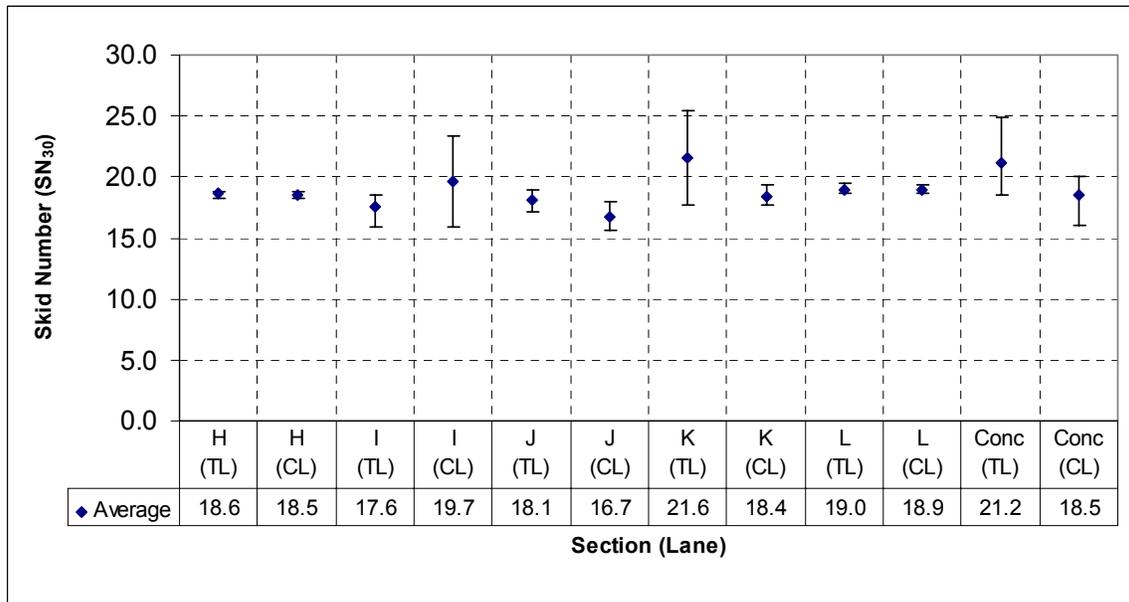


Figure 9. Maximum, Average, and Minimum Skid Measurements after Plowing for the Test (TL) and Control (CL) Lanes - Experiment II (3-04-02)

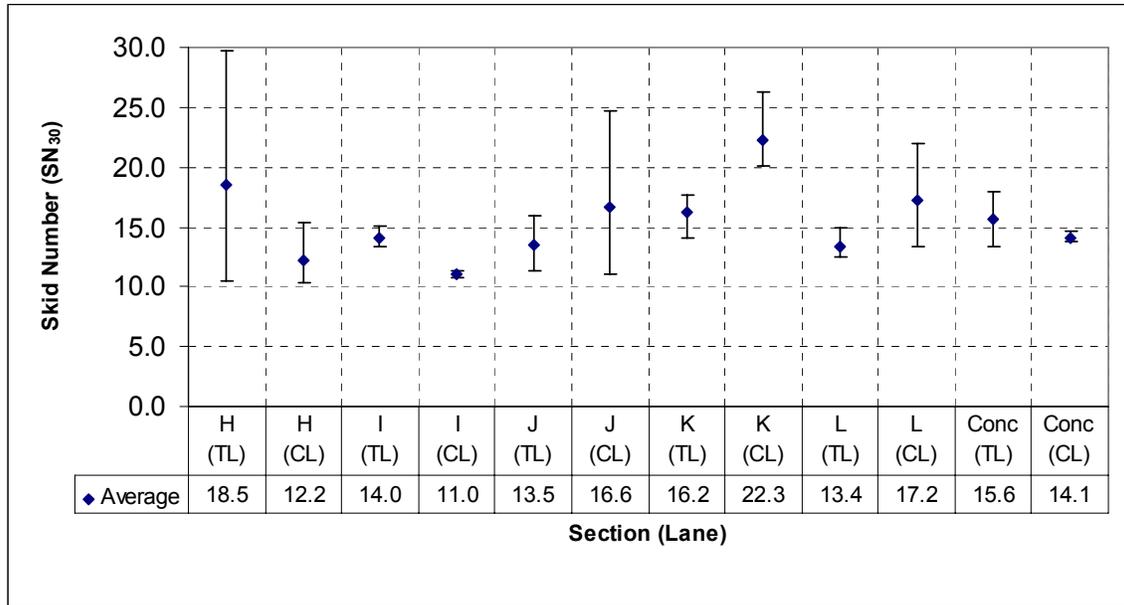


Figure 10. Maximum, Average, and Minimum Skid Measurements after Plowing for the Test (TL) and Control (CL) Lanes - Experiment III (3-06-02)

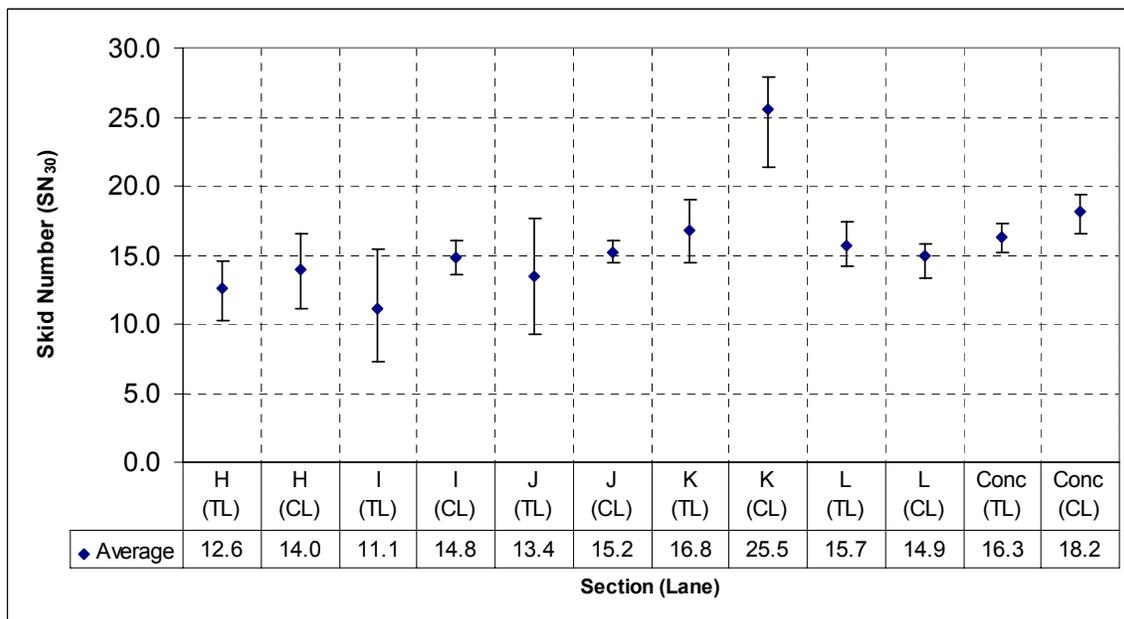
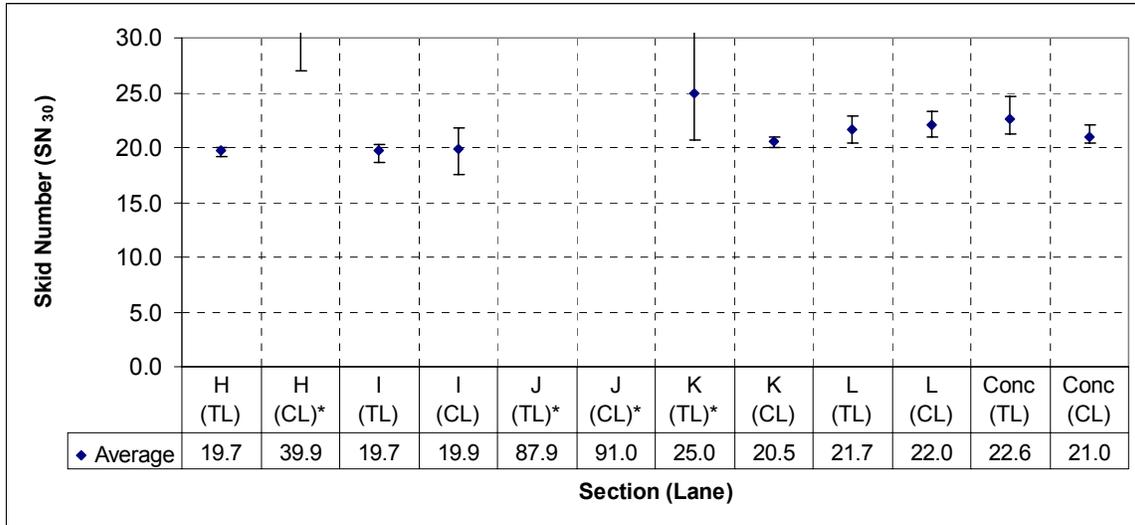


Figure 11. Maximum, Average, and Minimum Skid Measurements after Plowing for the Test (TL) and Control (CL) Lanes - Experiment IV (3-23-02)



* Indicates a test in which the snow coverage was not uniform

Figure 12. Maximum, Average, and Minimum Skid Measurements after Plowing for the Test (TL) and Control (CL) Lanes on - Experiment V (1-27-03)

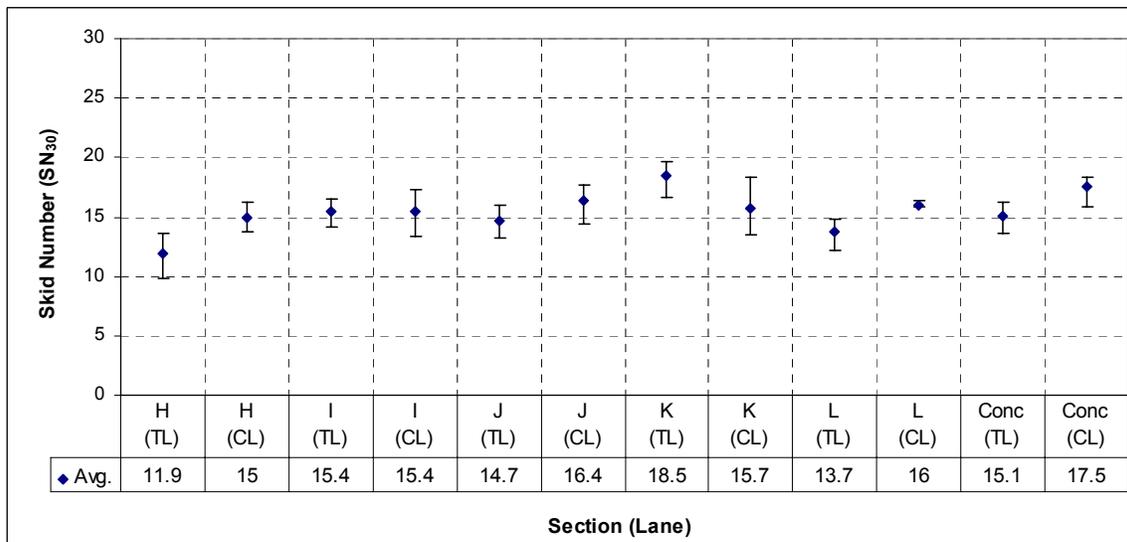


Figure 13. Maximum, Average, and Minimum Skid Measurements after Plowing for the Test (TL) and Control (CL) Lanes - Experiment VI (2-06-03)

The rankings based on subjective observations of Figures 8 through 13 were verified statistically using an Analysis of Variance (ANOVA). Table 7 shows the ANOVA for Experiment 1. As was previously observed, there are no statistically significant differences between the different surfaces or between the treated and untreated lanes.

Table 7. Analysis of Variance for Experiment I

Source of Variation	SS	Df	MS	F	P-value	F crit
Treatment	0.192	1	0.192	0.035	0.854	4.351
Surface Type	24.878	4	6.219	1.122	0.374	2.866
Interaction	12.085	4	3.021	0.545	0.705	2.866
Error	110.860	20	5.543			
Total	148.015	29				

Table 8 summarizes the finding for all experiments. This more detailed analysis indicates that, in some of the experiments, some sections performed better than others. For example, the control lane on Section K showed an SN that was slightly better than the rest of the section for experiment IV. This is attributed to inadequate snow coverage over that particular section. On the other hand, the test lane on Section H had very low skid number compared with the rest of the sections for experiment number VI. After these considerations, this analysis confirms that there was not a significant difference in the performance of the various sections.

Table 8. Summary of the Analysis of Variance for All Experiments

Experiment	Treatment		Surface Type		Interaction	
	P-Value	Significant	P-Value	Significant	P-Value	Significant
I	0.854	No	0.374	No	0.705	No
II	0.473	No	0.217	No	0.189	No
III	0.653	No	0.178	No	0.136	No
IV	0.007	Yes	0.000	Yes	0.062	No
V	0.258	No	0.136	No	0.186	No
VI	0.172	No	0.017	Yes	0.037	Yes

CONCLUSIONS

1. Discrete friction-measuring devices have limitations because they do not allow the variability of surface conditions to be assessed within a section. The use of friction-measuring devices that continuously measure pavement friction along the sections may produce better results.

2. At temperatures at and just below freezing, the artificial snow produced by the Smart Road snowmaking system may not be appropriate for evaluating the effectiveness of winter maintenance chemicals.
3. Under the temperature and precipitation conditions encountered, there were no significant differences in the performance of the different surface mixes tested. However, conditions encountered did not correspond to conditions normally encountered with natural snow.
4. The OGFC appears to have enhanced spray and splash performance while compared with the dense HMA surface mixes; however, a more objective measure of splash and spray characteristics of the surfaces is needed to quantify the beneficial effect of this type of mixes. No visual difference in performance was observed among the other mixes.

RECOMMENDATIONS

1. When using artificial snow, studies that depend on imitating the on-road attributes of natural snow, such as testing effectiveness of winter maintenance chemicals, should adhere to the ideal temperature-humidity guidelines for the snowmaking equipment.
2. If available for winter maintenance testing, the experiments should use friction-measuring devices that continuously measure pavement friction along the sections.
3. Additional experiments should be made to evaluate the following:
 - The skid resistance of OGFC and other wearing surfaces under natural winter driving conditions. The methodology developed by this study should be used for this evaluation.
 - The splash and spray characteristics of OGFC and other wearing surfaces under wet, non-freezing conditions. These experiments should use more objective criteria for determining visibility under traffic conditions.

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